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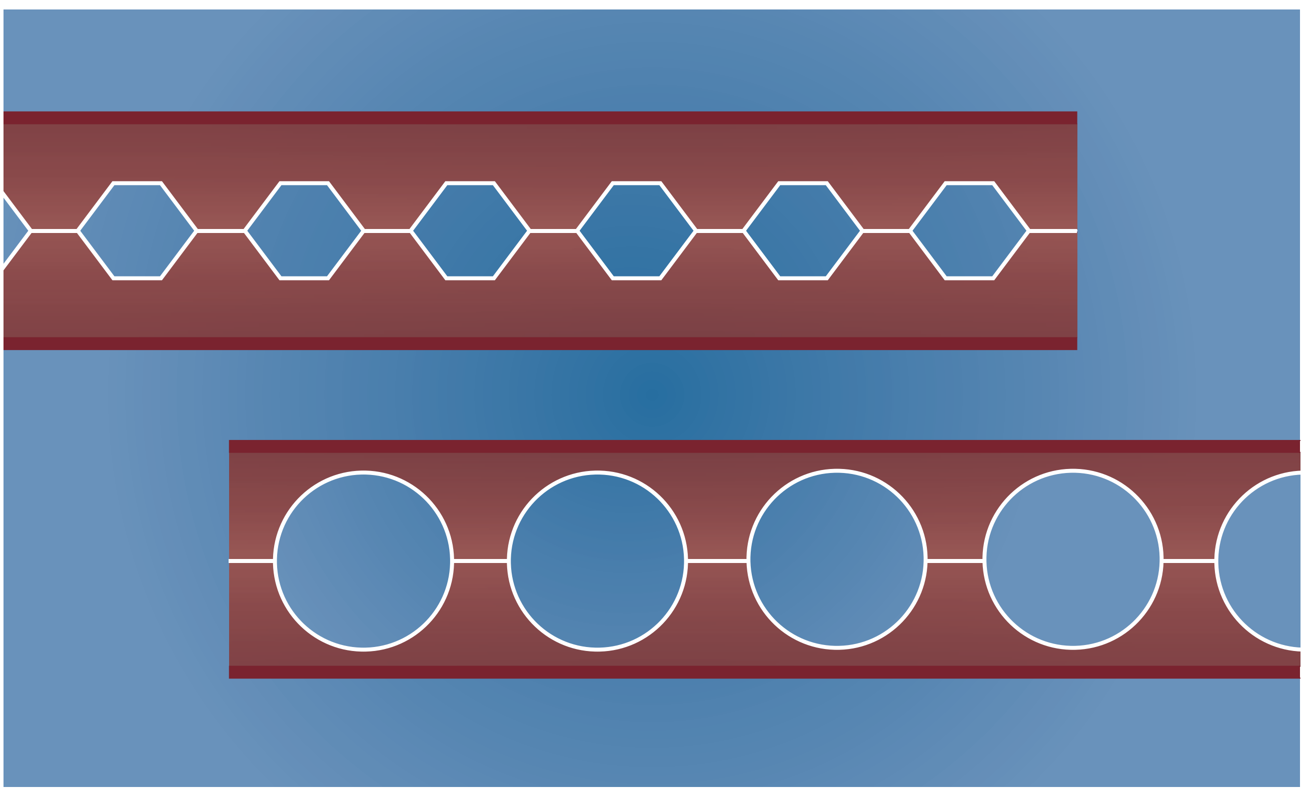
Steel Design Guide

Castellated and Cellular Beam Design



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Sameer S. Fares, P.E., S.E., P. Eng
New Millenium Building Systems
Hope, AR

John Coulson, P.E.
Integrity Structural Corporation
Houston, TX

David W. Dinehart, Ph.D.
Villanova University
Villanova, PA

AMERICAN INSTITUTE OF STEEL CONSTRUCTION

Printed in the United States of America

Authors

Sameer S. Fares, P.E., S.E., P. Eng is an engineer at New Millenium Building Systems, Hope, AR.

John Coulson, P.E., is a Principal and Vice President at Integrity Structural Corporation, Houston, TX.

David W. Dinehart, Ph.D., is a Professor at Villanova University, Villanova, PA.

Acknowledgments

The authors have been actively engaged in the design, research, and/or advancement of castellated and cellular beams for more than 10 years. Over that time frame, there have been many peers who have assisted the authors in bettering their understanding of the behavior of castellated and cellular beams. The support of Tim Bradshaw, Shawn Gross, Rebecca Hoffman, Billy Milligan, Serge Parent, Joe Pote, John Robins and Joseph Robert Yost has been invaluable and is greatly appreciated. Many thanks go to the graduate and undergraduate students who have conducted the experimental and analytical research at Villanova University sponsored by Commercial Metals Company, Inc.: Nicole Aloi (Hennessey), Dominic Borda, Michelle Dionisio (Callow), Jason Hennessey, Matthew Reiter, Jason Reither, Ryan Smoke and James Sutton. The authors are grateful to the reviewers of this document who provided insightful commentary:

Allen Adams
Leigh Arber
Reidar Bjorhovde
Jason Caldwell
Charles Churches
John Cross
David Darwin
Tom Faraone
Pat Fortney
Ted Galambos
Ed Garvin
Louis Geschwindner
Scott Goodrich
Jay Harris
Tony Hazel
Steven Hofmeister
Larry Kloiber
Roberto Leon
Tom Murray
Roger O'Hara
Davis Parsons
Daryll Radcliffe
Richard Redmond
David Ruby
Bill Scott
Robert Shaw
Victor Shneur
Derek Tordoff
Chia-Ming Uang

Finally, and most importantly, the authors thank their spouses and families for their support during the writing of this document.

Preface

This Design Guide provides guidance for the design of castellated and cellular beams based on structural principles and adhering to the 2016 AISC *Specification for Structural Steel Buildings* and the 14th Edition AISC *Steel Construction Manual*. Both load and resistance factor design and allowable strength design methods are employed in the design examples.

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Introduction

1.1 HISTORY

The idea of creating single web openings in wide-flange steel beams in order to pass service lines through the beam stems back to the early use of steel sections. The design of beams with web openings is addressed in AISC Design Guide 2, *Design of Steel and Composite Beams with Web Openings*, which explicitly notes that the design provisions do not apply to castellated beams—beams with expanded web sections that included repeating openings (Darwin, 1990). In this document, castellated beams are defined as steel beams with expanded sections containing hexagonal openings. Cellular beams are defined as expanded steel sections with circular openings.

Beams with expanded web sections with repeating web openings were first used in 1910 by the Chicago Bridge and Iron Works (Das and Srimani, 1984). This idea was also developed independently by G.M. Boyd in Argentina in 1935 and was later patented in the United Kingdom (Knowles, 1991). In the 1940s, the use of castellated and cellular beams increased substantially, in part due to the limited number of structural sections that the steel mills could fabricate in Europe. Steel mills could efficiently produce a number of larger section sizes by manually expanding beams because of low labor-to-material cost ratios. However, steel mills in the United States did not experience the same section limitations and low labor costs as the mills in Europe; consequently, the fabrication of such beams was not economically efficient. As a result, the use of castellated and cellular beams diminished until automated manufacturing techniques became available. The improved automation in fabrication, coupled with the need for architects and structural engineers to search for more efficient and less costly ways to design steel structures, has resulted in the use of castellated and cellular beams in the United States. An increase in use of expanded sections has occurred around the world and contributed to the formation of the International Institute of Cellular Beam Manufacturers in 1994 to develop, establish and maintain standards for the design and manufacturing of castellated and cellular beams worldwide.

1.2 MANUFACTURING

Castellated and cellular beams are custom designed for a specific location on a specific project. The process by which castellated and cellular beams are fabricated is similar, but not identical. Castellated beams are fabricated by using a computer operated cutting torch to cut a zigzag pattern along the web of a wide-flange section. The step-by-step process of manufacturing a castellated beam is presented in Figure 1-1. Once the section has been cut in the appropriate pattern (a), the two halves are offset (b). The waste at the ends of the beam is removed (c), and the two sections are welded back together to form the castellated section (d). A full or partial penetration butt weld is then typically made from one side of the web, without prior beveling of the edges if the web thickness is relatively small. A photograph of the manufacturing process of a castellated beam is shown in Figure 1-2.

Cellular beams are fabricated in a similar manner using a nested semicircular cutting pattern. In order to achieve the repeating circular pattern, two cutting passes are required, as shown in Figure 1-3. The two cutting passes increase the handling of the steel during the manufacturing process; consequently, the time to produce a cellular beam is slightly greater than that of a castellated beam. The cuts are made in a circular pattern instead of the zigzag used for the castellated beams. The circular cutting produces additional waste as compared to castellated beams, as shown in Figure 1-3(b). Once the two cuts have been made, the two halves that have been created are offset and welded back together to form a cellular beam. A photograph of the manufacturing process of a cellular beam is presented in Figure 1-4.

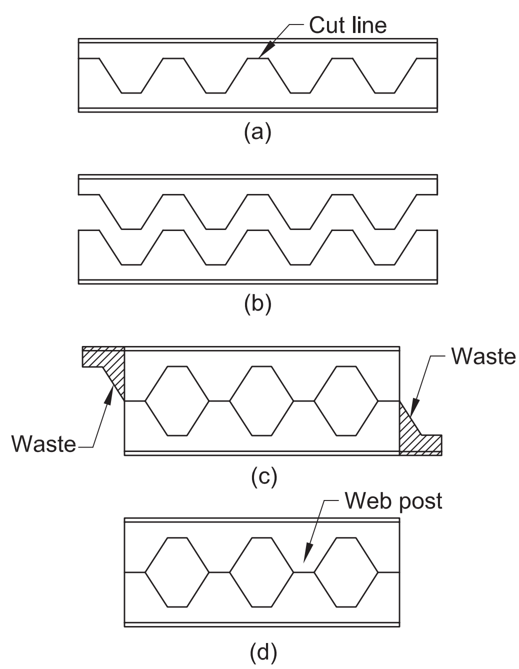

Fig. 1-1. Manufacturing of a castellated beam.

Fig. 1-2. Cutting of a castellated pattern.

1.3 NOMENCLATURE

Typical nomenclature for a steel section indicates the shape type, the approximate depth, and the approximate weight of the shape per linear foot. For example, a W8×10 represents a wide-flange section with a depth of approximately 8 in. and a nominal weight of 10 lb/ft. A similar nomenclature is used for castellated and cellular beams. Castellated beams are represented by CB, while cellular beams are noted as LB. The number representations are identical to those of standard steel sections. For example a castellated and cellular beam constructed from a W8×10 root beam is called out as a CB12×10 and LB12×10, respectively, as the depth is approximately one and half times that of the root beam and the weight is the same as the root beam. Under certain conditions, it is beneficial to produce an asymmetric section. In this case, the nomenclature for these sections is based on the two different root beams used to make the castellated or cellular section. For example, if the root beam for the top tee of the castellated or cellular beam is a W21×44 and the root beam for the bottom is a W21×57, then the castellated and cellular beam call outs would be CB30×44/57 and LB30×44/57, respectively. The first number presents the approximate depth and the second pair of numbers provides

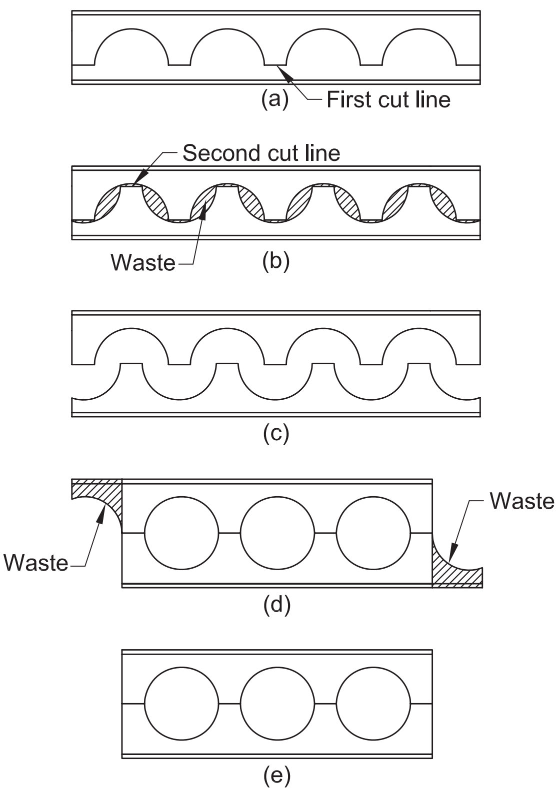

Fig. 1-3. Manufacturing of a cellular beam.

Fig. 1-4. Second cutting of a cellular pattern.

the nominal weight of the root beam used for the top of the section followed by a forward slash and the nominal weight of the root beam used for the bottom of the section. The weight per foot of the resulting asymmetric beam is the average of the two numbers. The use of asymmetric sections is discussed in further detail in Section 2.2.6.

1.4 INTRODUCTION OF DESIGN GUIDE

Although the use of castellated and cellular beams around the world is becoming more commonplace and there is a growing body of literature on the topic, there are very few publications that include comprehensive design recommendations. This Design Guide presents the state of the practice for the design of castellated and cellular beams in the United States. The Guide provides a unified approach to the design of castellated and cellular beams for noncomposite and composite applications. Chapter 2 presents information pertaining to appropriate applications for castellated and cellular beams, including advantages, efficiencies, and limitations of use. The differences between designing traditional beams versus those with web openings are identified in Chapter 3, along with the detailed procedures for designing castellated and cellular beams in accordance with the 2016 AISC *Specification for Structural Steel Buildings*, hereafter referred to as the AISC *Specification* (AISC, 2016). The procedures presented include both noncomposite and composite design for both castellated and cellular beams. Chapter 4 presents detailed design examples conforming to the procedures presented in Chapter 3. A detailed listing of the symbols used throughout the Design Guide is supplied at the end of the document, as is a complete list of references cited in the Design Guide and a bibliography of publications for further reading.